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SIGNAL PROPAGATION AT 400 kHz USING AN OAK TREE WITH A HEMAC AS AN ANTENNA

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40 kHz						
Electromagnetic						
Jungle Propagation						
Scatter						

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TECHNICAL REPORT ECOM-3504

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by

K. Skrivseth

NOVEMBER 1971

DA Work Unit No. 1H6 62701 A448-06-181

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ABSTRACT

A HEMAC (Hybrid Electromagnetic Antenna Coupler) is used to couple r-f energy in the medium frequency range (400-425 kHz) to an oak tree that is used as an antenna. A discussion of the measured impedance data and the effects of the nearby terrain is presented along with the conclusions reached.

1. Introduction

In the effort to utilize the electrical properties of live vegetation to advantage for jungle radio communications, HEMAC's[1] have been shown to be useful in coupling RF energy from transmitters to forest tree antennas. Prior to this report, most of the work was done in the Lebanon State Forest, New Jersey at High Frequency. There were indications as early as April 1969 that a lower frequency operation of HEMAC's might prove more satisfactory, and an initial investigation was begun in June 1970 in the medium frequency range, specifically 400-425 kHz. The investigation was conducted at the Earle Test Area.

As will be shown, an unexpected strong directional transmitted pattern appeared at 400 kHz when the HEMAC was utilized at one particular forested site at Earle Test Area.

2. Test Setup

Transmitter

A HEMAC was placed at a 3 foot height around the trunk of a large oak tree at a forested site in the Earle Test Area. Power for the transmitter was supplied by a gasoline generator. Figure 1 shows the transmitter site and Figure 2 is a circuit diagram. The HEMAC toroid used in nearly all tests has 23 turns with a one foot coil diameter and a four foot overall diameter. RF power input to the HEMAC was about 35 watts. Transmissions were made using amplitude modulation with a pulsed 400 Hz tone, providing about 50% modulation of the carrier. This enabled the signal to be recognized with certainty at the receiver.

Receiver

A National HRO-500 Communications Receiver was used along with a Jeep-mounted 15 foot whip antenna shown in Figure 3. The HRO-500 has a separate "Low Frequency Tuning Head" for optimum antenna matching to the receiver. The receiver was transported in the Jeep to locations where only a marginal signal could be received. A map of the marginal received signal locations is shown in Figure 4.

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[1] A HEMAC (Hybrid Electromagnetic Antenna Coupler) is a toroid which is used to couple RF energy between a transmitter and a forest environment. The toroid carrying RF current causes a field to be radiated with the aid of the tree on which the toroid is mounted. (ECOM Patent Application #19084)

3. Test Results

An unexpected pronounced lobe to the south appears in the antenna pattern of Figure 4. (The lobe may extend to the southeast or east but there were no offshore measurements made.) To the south the 400 kHz signal was received over 30 miles from the transmitter, compared with 5 miles or less to the north. Directional patterns have been observed at HF using HEMAC's both in Lebanon State Forest and at Earle Test Area, but there has never been this strong an effect. Thus some phenomenon which has a strong directional effect at 400 kHz does not significantly affect HF experiments performed at the same transmitter location.

Input impedance measurements of the HEMAC mounted on the tree showed that the HEMAC is mostly inductive in the frequency range 1 to 2500 kHz. There should thus be no current standing waves in the windings of the toroid at 400 kHz. In other words, an RF current of 1 amp rms at the toroid terminals would indicate 1 amp rms of RF current at any arbitrary point in the windings. A directional effect due to current variations in the HEMAC windings can thus be discounted as a cause for the lobed pattern. Spacing of the windings was kept uniform during all tests described here.

RF measurements made at the receiver sites indicate a background variation of less than 2 db for all sites. In a further attempt to find the cause for the highly directional pattern of Figure 4, the forest height and terrain variations in the vicinity of the original transmitter site were studied, resulting in two vertical plane cross-sections at the transmitter site (Figure 5). There is little variation in the east-west direction, of forest height, terrain, or elevation. The average forest height is about 45 feet. In the north-south direction, however, there are significant differences in these parameters. It happens that the transmitter site is adjacent to the border between two types of forest. To the north the forest height averages about 45 feet and the trees are primarily oak. The ground appears damp to the eye, and in fact the low terrain area 150 yards north of the transmitter has standing water for several days following a heavy rain. To the south, the average forest height is about 25 feet, significantly 20 feet less than to the north. The soil is drier and more sandy than to the north. About half of the vegetation to the south is pine.

The transmitter tree was eliminated as the sole cause for the pattern lobe. Non uniform tree shape and proximity to other trees are expected to cause a minor directional pattern, but in this case the transmitter setup was moved to a second tree about 50 meters east of the original transmitter site resulting in no loss of signal strength at the southern most receiver site.

Moving the transmitter and HEMAC about ½ mile southwest of the original transmitter site to a large oak tree, however, had a definite effect. The radiated 400 kHz pattern from this third site was much more omnidirectional. In the vicinity of this third site the forest height and density is fairly

uniform in all directions, and the terrain is nearly flat. The forest density in the area is lower than at the original site, and average tree height is about 30 feet. The soil is relatively sandy.

4. Conclusions

If the causes for a directional pattern when using a HEMAC at medium frequency can be uniquely determined, the property may well be used to advantage in future work. Some considerations are given below.

The forest height difference between the north and south at the first test area (Figure 5) could enhance the 400 kHz signal to the south by several means. The effective antenna height to the south should be about 20 feet greater than to the north, which would mean enhancement of any horizontally polarized field component, at least, to the south. The antenna near field losses should be less to the south, due to less obstructing vegetation in that direction. These arguments do not, however, explain the almost omnidirectional character of HF experiments performed at the same site with similar apparatus.

It may be that a wet low area 150 yards to the north of the original site (and extending from there to the east and west) is a factor, acting as a reflecting element (Figure 5). Since a quarter wavelength at 400 kHz in free space is 187 meters or 204 yards, a "reflector spacing" of 150 yards would not be unreasonable for antenna construction. This reflection possibly would also account for the differences between 400 kHz propagation and HF propagation characteristics, since for HF the 150 yard spacing is over one wavelength.

Another possibility is some effect due to variations in ground constants with depth in the soil, a variation which would necessarily occur both below the depth of penetration of HF electromagnetic waves, and still well within the skin depth at 400 kHz. Skin depth is nearly inversely proportional to the square root of frequency, so the skin depth at 4 MHz, for example, would be less than 1/3 the 400 kHz skin depth (idealized for invariant ground constants and assuming a moderately good conductor.)[2]

Other cases may well appear if a comprehensive numerical field strength study is made. A numerical study would help eliminate such variables as human error and changing background noise with time and location. The scope of such a study should include such areas as directivity as a function of frequency, and received signal polarization versus azimuth from the transmitter site. The study should point towards a clear determination of the usefulness of HEMAC's at various frequencies in helping to reduce the problems of communications in a dense forest environment.

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[2] For sandy soil ($\sigma = 2 \times 10^{-3}$ mho/meter, $\varepsilon_r = 10$, $\mu_r = 1.$), a typical calculated depth of penetration is 8.7 meters for 4 MHz and 18.7 meters for 400 kHz.

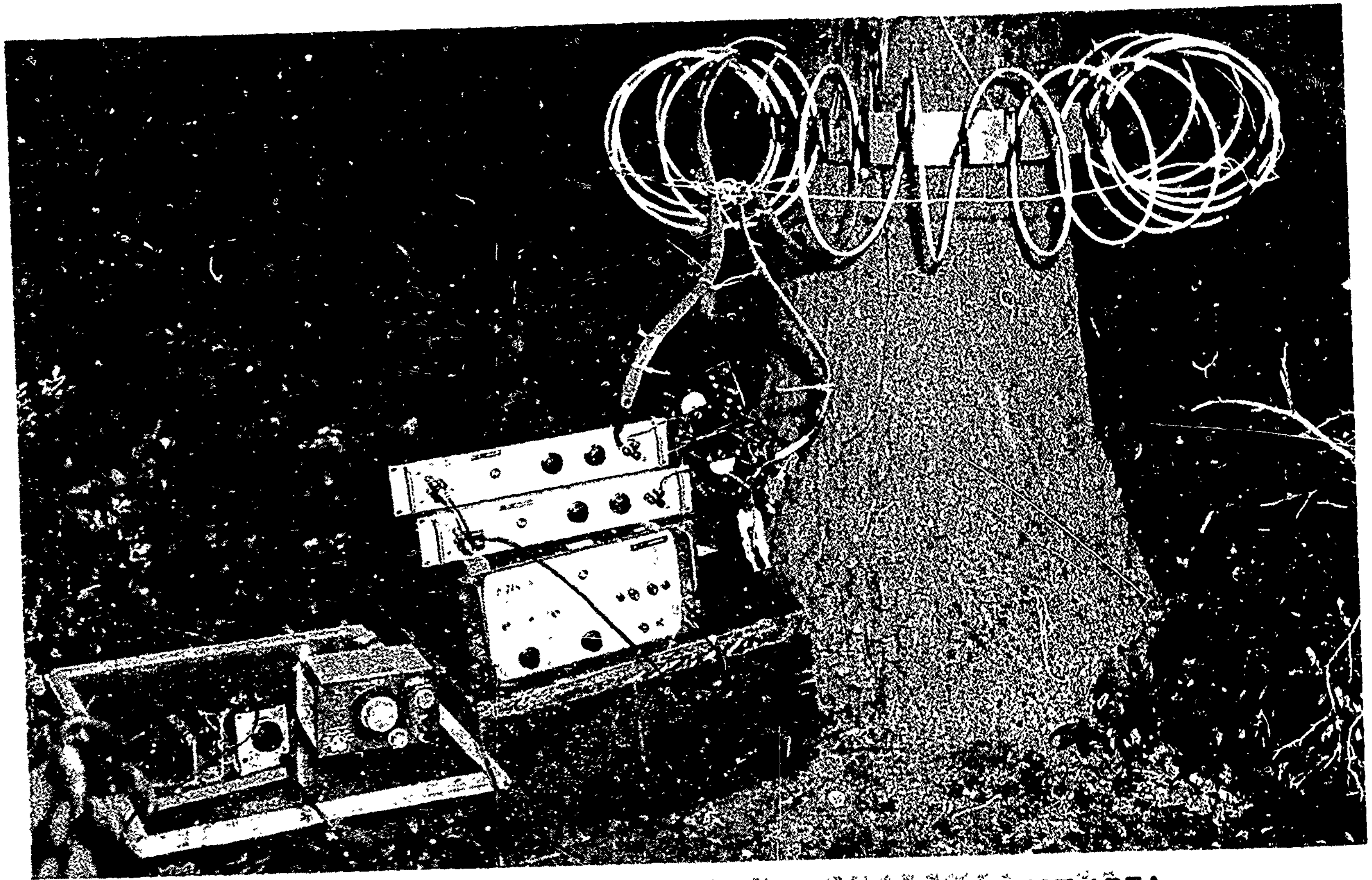


FIG. 1 PHOTO OF TRANSMITTER SITE IN EARLE TEST AREA

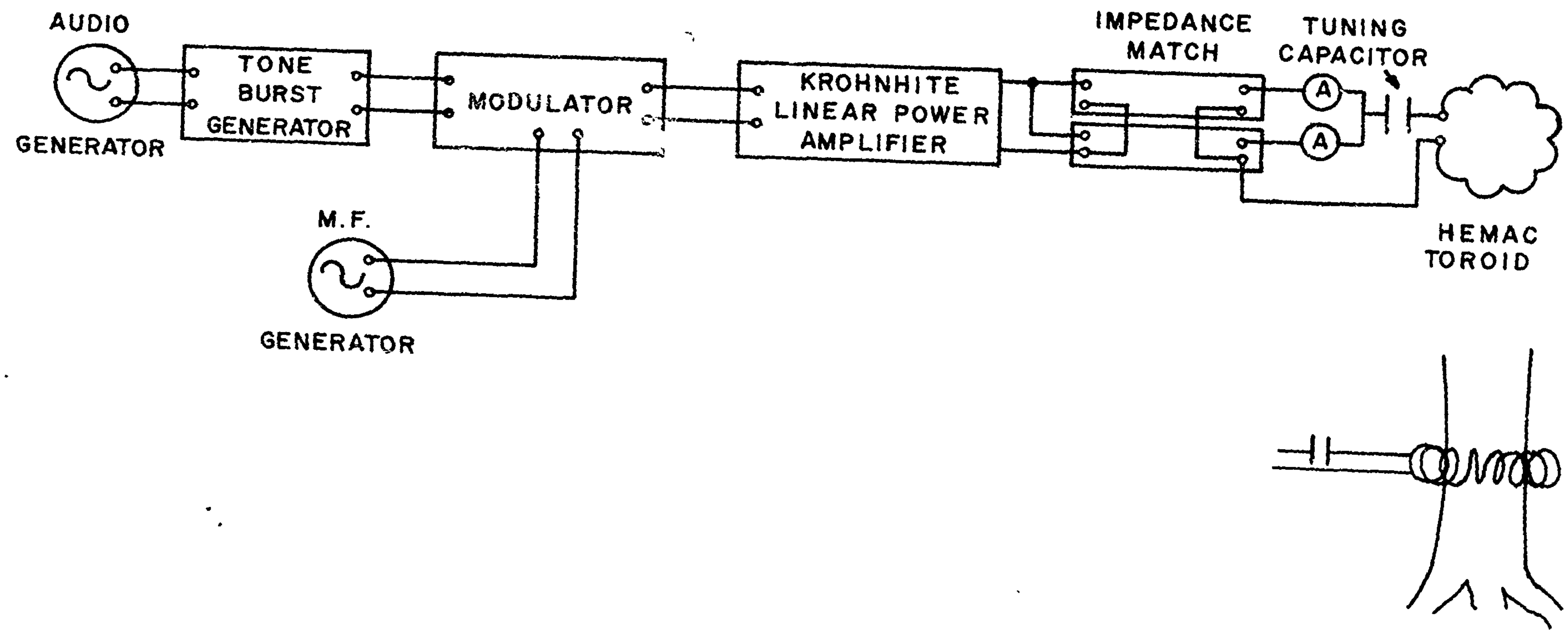


FIG. 2 CIRCUIT DIAGRAM OF TRANSMITTER SETUP

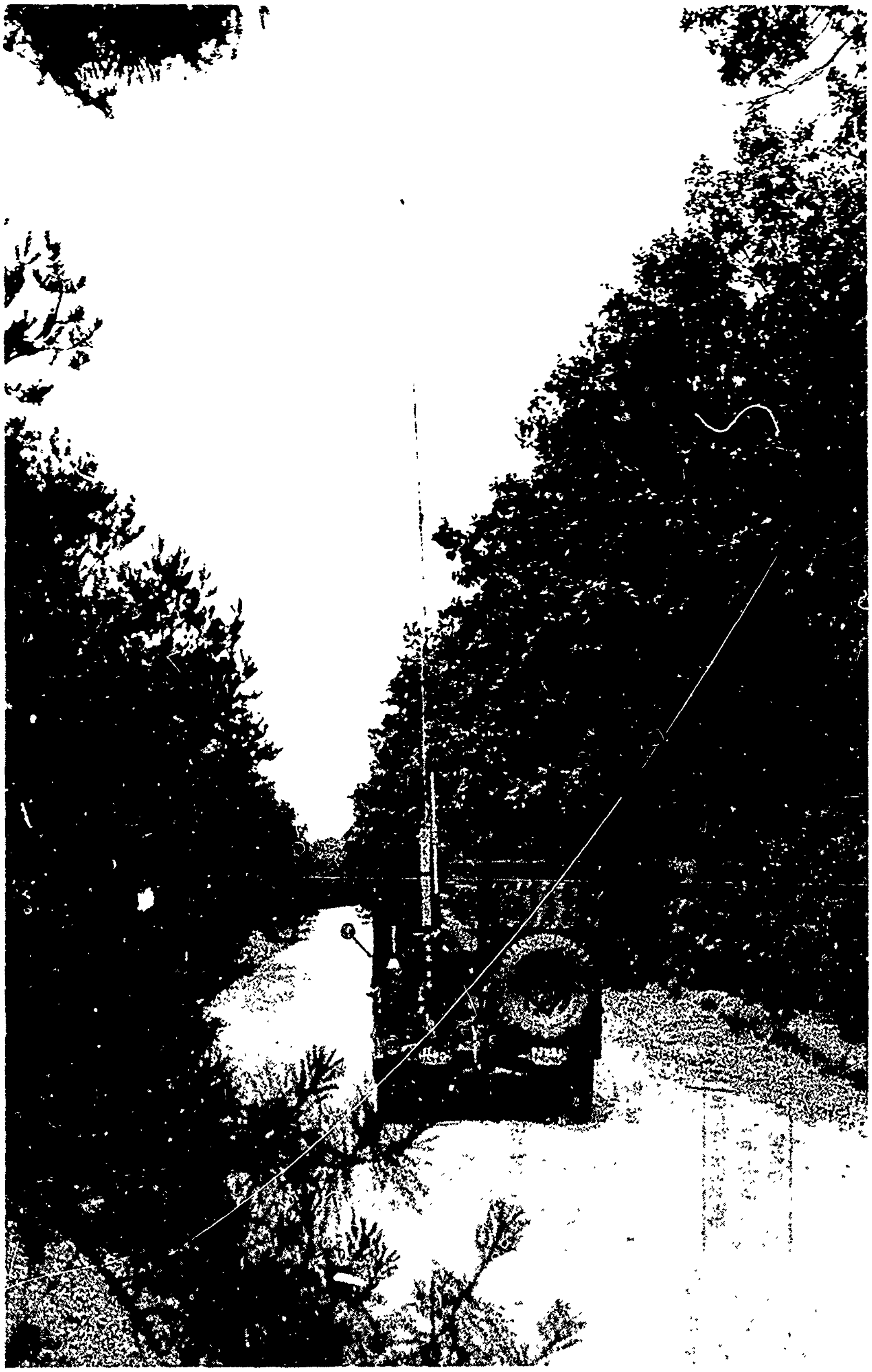


FIG. 3 PHOTO OF JEEP-MOUNTED 15 FOOT WHIP RECEIVING ANTENNA

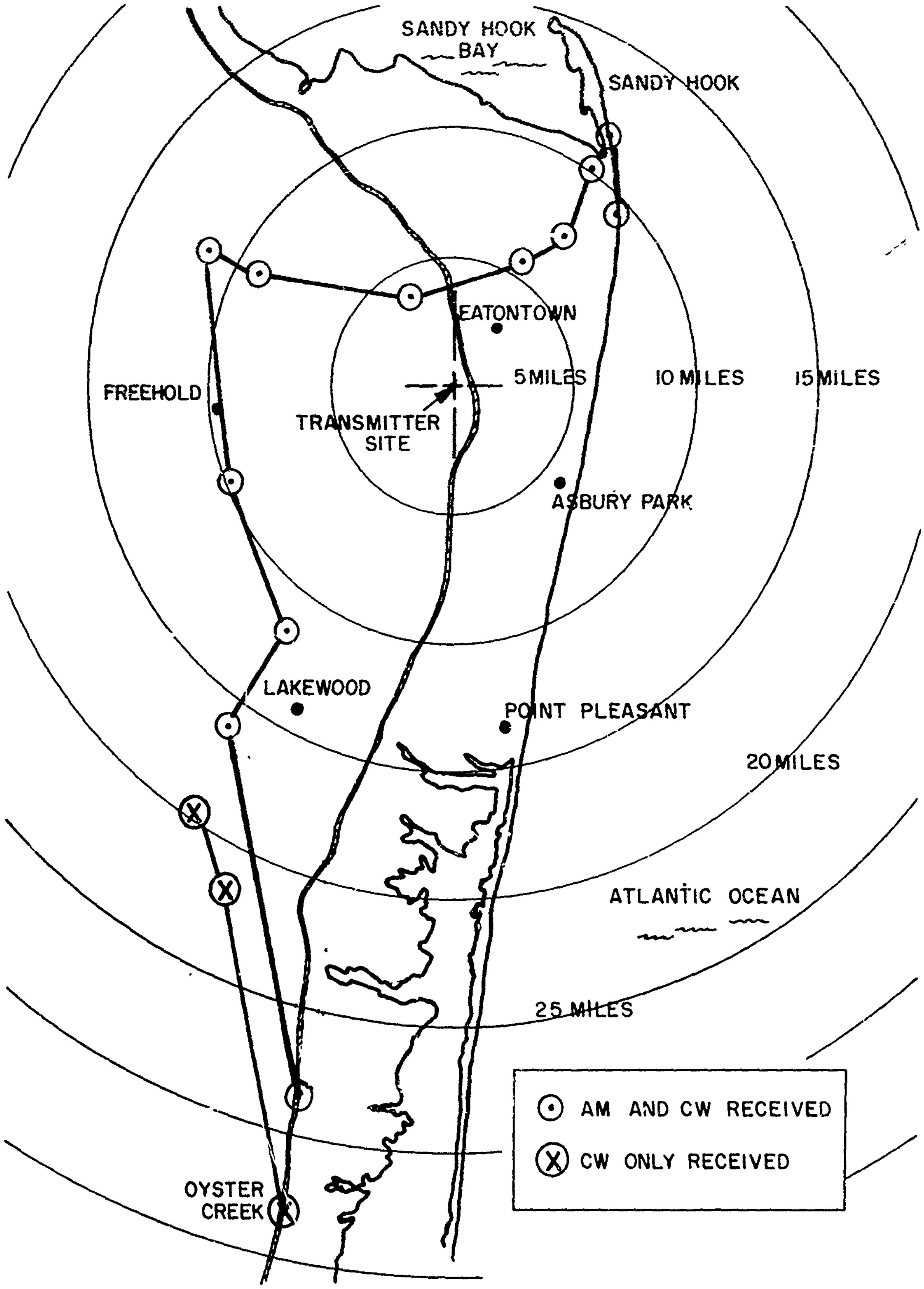
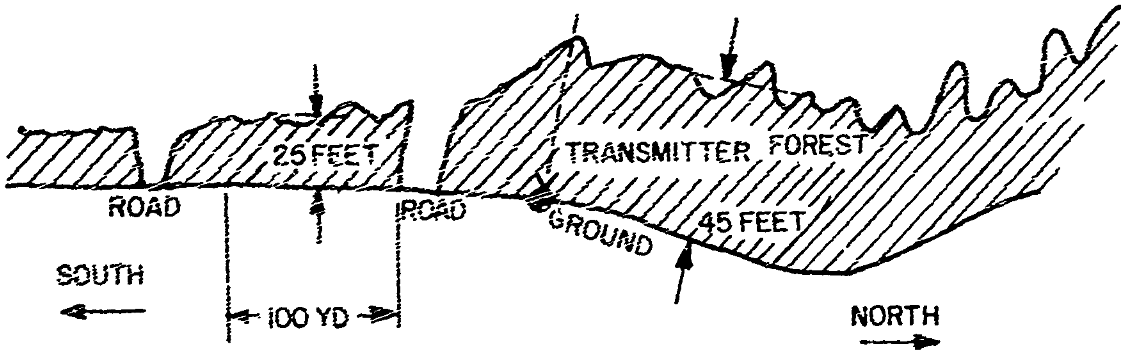


FIG.4 MAP OF RECEIVED SIGNAL LOCATIONS:
XMTR TOROID TREE
RCVR WHIP JEEP

NORTH SOUTH VERTICAL SECTION THROUGH TRANSMITTER SITE

(NOT TO ACCURATE SCALE)



EAST WEST VERTICAL SECTION THROUGH TRANSMITTER SITE

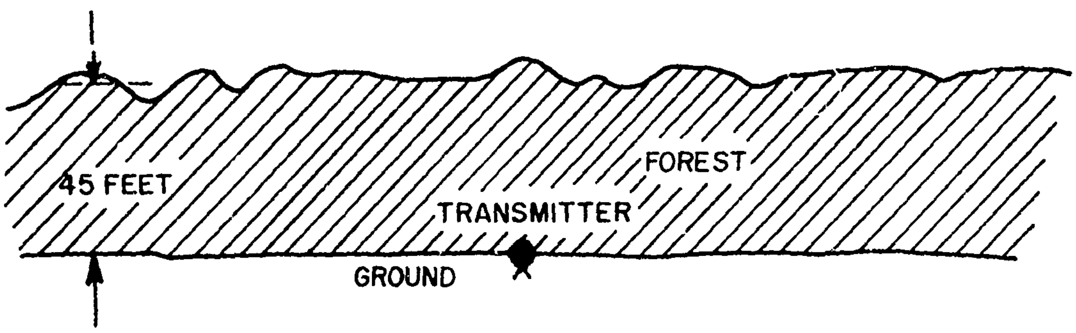


FIG. 5 TERRAIN CROSS-SECTION IN THE VERTICAL PLANE AT THE HEMAC TRANSMITTER SITE